AEDC-TR-65-268

STUDY OF THE ENERGY ADDITION PROCESS IN A D-C ARC-JET

R. J. Bryson and J. P. Fröhlich

ARO, Inc.

April 1966

Distribution of this document is unlimited.

ROCKET TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

STUDY OF THE ENERGY ADDITION PROCESS IN A D-C ARC-JET

R. J. Bryson and J. P. Fröhlich
ARO, Inc.

FOREWORD

The work reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Program Element 61445014, Project 8951, Task 895105.

The research was conducted by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the AEDC under Contract AF 40(600)-1200. The work was conducted under ARO Project Number RW3501 in the Propulsion Research Area (R-2A-5) of the Rocket Test Facility (RTF), and the report was submitted by the authors as partial results of these research efforts on November 24, 1965.

The authors wish to acknowledge many helpful discussions held with W. K. McGregor, ARO, Inc., during the course of this investigation. Also the help of C. E. Redman, ARO, Inc., in developing the force measuring system is greatly appreciated.

This technical report has been reviewed and is approved.

Terry L. Hershey
Captain, USAF
Aerospace Sciences Division
DCS/Research

Donald R. Eastman, Jr.
DCS/Research

ABSTRACT

The thrust produced by a d-c arc-jet plasma generator operating with argon was measured and used to determine the division of the energy added to the gas between that which produced excitation and ionization and that which served to increase the translational energy of the gas. Energy division predicted by the Rayleigh heat addition theory was compared with the experimental determination and was found to be in fair agreement (15 to 30 percent). The plasma generator was operated at electrical power inputs ranging from 1.9 to 3.8 kw. Energy losses to the electrodes amounted to about 30 percent, so that about 70 percent of the total electrical energy input was actually added to the gas. The amounts of energy added to the gas ranged from 220 to 440 Btu/lb_m at an argon flow rate of 0.00527 lb_m/sec. On the average, only about 40 percent of this energy addition was utilized to increase the total translational energy of the gas, and the remainder served to produce electronic excitation and ionization.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A	Cross-sectional area of anode
a	Sonic velocity
c_p	Specific heat at constant pressure
F	Thrust
F_i	Ideal thrust
M	Mach number
m	Mass of an argon atom
$\dot{m}$	Mass flow rate
p	Static pressure
p_o	Total pressure
Q_E	Electrical energy supplied to generator
Q_{ei}	Energy available for excitation and ionization
Q_G	Energy added to gas
Q_{tr}	Total translational energy addition
Q_{tr_i}	Ideal translational energy addition
Q^*	Energy added which produces choked flow
R	Specific gas constant
T	Static temperature
T_o	Total temperature
V_i	Ionization potential
v	Velocity
α	Degree of ionization
γ	Ratio of specific heats
ρ	Density

SUBSCRIPTS

1	Station 1 at entrance to anode throat section
cell	Test cell conditions

SECTION I
INTRODUCTION

Arc-jet plasma generators have been used extensively during the past several years for hypervelocity, low-density, wind tunnels, as thrustors for space propulsion, and in other applications where a high enthalpy gas is required. Design of such devices requires a knowledge of the division of energy added in different forms, i.e., thermal and kinetic energy, electronic excitation and ionization energy, and also for polyatomic gases, the rotational, vibrational, dissociational energy. Generally such knowledge is not available because the energy addition mechanism is a very complex process accompanied by electron temperatures much in excess of gas temperatures (Ref. 1). The objective of the work reported here was to experimentally determine the energy addition in the translational mode (thermal and directed kinetic energy) of a monatomic gas, and thus distinguish it from the energy producing excitation and ionization.

The study was conducted in the Gas Kinetics Laboratory of the Rocket Test Facility, using a small arc-jet plasma generator with a constant area throat anode, and operating in a vacuum test cell, R-2A-5b, using argon as the working fluid. The total amount of energy absorbed by the gas was determined from an energy balance on the entire apparatus. The thrust produced by the generator is related to the energy addition required to produce choked flow. If the degree of ionization of the gas is small enough so that the heat capacities are unaffected by it, then the energy addition which produces choked flow is identical to the energy added to the gas in the total translational mode. The energy producing excitation and ionization does not contribute to the thrust under these conditions. It was therefore possible to determine the amount of energy addition in the translational mode by measuring the thrust produced by the generator. The difference between the total energy added to the gas and the total translational energy addition then represents the amount of energy available for excitation and ionization.

Experimental values of thrust produced by the generator were obtained over a limited range of energy additions at a constant gas flow rate. On the average, about 70 percent of the electrical energy supplied to the generator was absorbed by the gas. The fraction of the total energy added to the gas available for excitation and ionization was found to be, on the average, about 60 percent, corresponding to overall degrees of ionization of up to 2 percent, under the assumption that all this energy produces ionization.

SECTION II
APPARATUS AND PROCEDURE

The experimental apparatus consisted of a low-pressure test cell, an arc-jet plasma generator, the necessary instrumentation for measurement of generator operating conditions, and a force measuring system to measure the thrust.

2.1 TEST CELL

The low-pressure test cell (Fig. 1) is a vertically mounted section of 30-in. -diam cylindrical pipe closed on one end and connected to a pumping system on the other. The pumping systems available are mechanical vacuum pumps, which can maintain the cell at approximately 2 mm Hg with secondary flow of approximately 0.0050 lb_m/sec, and the RTF exhaust system in conjunction with an air ejector, which can operate the cell at approximately 0.5 mm Hg with a similar secondary flow.

2.2 ARC-JET PLASMA GENERATOR AND INSTRUMENTATION

The arc-jet plasma generator used is of the Gerdien type and is shown in Fig. 2. The front and back plates are made of brass, and the main body is made of a ceramic electrical insulator. The rear plate contains a pressure sealed opening for the cathode, a tap for measuring the chamber pressure, and a gas supply opening. Gas is introduced through a perforated plate to ensure uniform distribution around the chamber. The front plate is provided with a water-cooled jacket into which replaceable copper anodes may be inserted. The cathode assembly consists of two concentric tubes, with cooling water flowing through the annulus, and a copper heat sink threaded on the end into which the tungsten cathode material is force fitted. The cathode assembly may be moved axially to provide different arc gaps. The following parameters were measured:

Gas supply pressure	0- to 200-in. HgA Bourdon gage
Gas flow rate	0- to 10-scfm Brooks rotameter
Gas inlet temperature	Hg thermometer
Generator chamber pressure	0- to 15-psia Bourdon gage
Arc voltage	Voltmeter
Arc current	Millivoltmeter and shunt

Cooling water flow rate	Time required to fill a given volume
Cooling water inlet and outlet temperature	Dial thermometer
Cell pressure	McLeod gage

2.3 FORCE MEASURING SYSTEM

A rotating hollow shaft in the force measuring system transfers the force produced by the generator through the cell wall to the end of a small cantilever beam mounted outside the cell. A strain gage is attached to the cantilever beam to detect changes in beam deflection, and the output voltage is monitored on a recording potentiometer. The rotating shaft (Fig. 3) is made of a stainless steel tube with arms clamped on each end. The generator is mounted vertically on one arm, and the other is equipped with a Teflon® capped screw which bears on the end of the cantilever beam through a Teflon pad. The shaft rotates in bearings fitted into a larger tube which is welded to a plate to mount the assembly to the cell access port flange. The area between the shaft and tube is sealed with a Teflon O-ring. The generator instrumentation and supply leads are fed through the shaft to the outside, and the end of the shaft is capped to prevent leakage into the cell. This arrangement eliminates drag produced by the electrical leads and plumbing. To prevent axial motion of the shaft due to atmospheric pressure on the end when the cell pressure is reduced and to minimize frictional effects, a small steel pin is inserted between the end of the larger tube and the arm clamped on the outside of the shaft. This pin is free to move in any direction except along its axis.

2.4 PROCEDURE

Generator operating parameters for each operating condition are obtained by the following procedure. The generator is started, the desired gas flow rate and electrical energy input level are set, and the generator is allowed to operate until all transients have dissipated (about 5 min). At this point the previously mentioned parameters are recorded, and the position of the strain-gage potentiometer indicator is noted. The generator power and gas flow are then cut off, and the potentiometer position is again noted. The difference between the two positions is proportional to the thrust produced by the generator. After the desired number of generator operating conditions has been obtained, a thrust versus potentiometer position calibration is performed by applying known weights to the generator and noting the potentiometer position. Since the strain gage is operated in the region of linear response, the calibration curve is a straight line, and its slope is the proportionality constant between generator thrust and potentiometer position. For each calibration, the indicator position for a given applied weight can be repeated within ±3 percent. The range of the thrust measuring apparatus is 0.01 to 5 lb_f.

To determine the portion of the electrical energy which is added to the gas, Q_G, an energy balance is performed on the generator. The amount of energy absorbed by the cooling water is determined from the water flow rate, its specific heat capacity, and the change in the water temperature. This energy is then subtracted from the input electrical energy, and the remaining amount is assumed to enter the gas. On a per pound of gas basis this appears in equation form as

$$Q_G = Q_E - \frac{(c_{p_w})(\dot{m}_w)(\Delta T_w)}{\dot{m}_g} \tag{1}$$

For these experiments, the gas flow rate was maintained as constant as possible (at 0.00527 lb_m/sec), and the electrical power input was varied from 1.9 to 3.8 kw. Argon gas was used exclusively as the working fluid, chamber pressures ranged from 7.58 to 9.20 psia, and a 0.250-in. constant diameter sonic nozzle anode was used. Q_G is presented as a function of Q_E in Fig. 4. (Each set of points represents data obtained during one continuous run.) This graph indicates that approximately 70 percent of the electrical energy supplied to the generator is absorbed by the gas.

SECTION III
ANALYSIS

It is observed experimentally that the plasma issuing from the generator is supersonic. This implies that the flow is choked somewhere in the anode throat as a result of the energy addition. Visual evidence indicates that in this generator very little energy, if any at all, is added to the gas downstream of the anode exit. This leads one to believe that the flow is choked very near the anode exit plane. These two conditions are used in this analysis along with the assumptions that the flow is one-dimensional as it passes through the sonic station, that the plasma behaves like an ideal gas, and that the mean degree of ionization is small so that the plasma may also be considered to behave like a calorically perfect gas. The validity of these assumptions will be analyzed in the light of the results.

The thrust produced by the generator, F, is given by

$$F = \dot{m}\, v^* + (p^* - p_{cell})\, A \tag{2}$$

By using the mass flow equation,

$$\dot{m} = \rho^*\, v^*\, A \tag{3}$$

the equation of state,

$$p^* = \rho^*\, RT^* \tag{4}$$

the thermodynamic relationship,

$$c_p = \frac{\gamma}{\gamma - 1}\, R \tag{5}$$

the condition of choked flow,

$$v^* = Q^* = \sqrt{\gamma RT^*} \tag{6}$$

and the isentropic temperature relationship at the sonic throat,

$$T^* = \left(\frac{2}{\gamma + 1}\right) T_o^* \tag{7}$$

then the thrust produced by the plasma generator can be expressed as a function of the total temperature at the sonic throat and measured flow parameters in the form

$$F = \dot{m}\sqrt{2\left(\frac{\gamma^2 - 1}{\gamma^2}\right)}\, \sqrt{c_p\, T_o^*} - p_{cell}\, A \tag{8}$$

The energy addition required to produce choked flow is

$$Q^* = c_p\, T_o^* - c_p\, T_{o_1} \tag{9}$$

where $c_p T_{o_1}$ is the total enthalpy of the gas upstream of the heating zone. Since this energy addition merely serves to increase the total temperature of the gas, it can be identified with the energy added in the form of total translational energy, Q_{tr} (i. e., the sum of thermal and directed kinetic energy). The thrust produced by the plasma generator is thus related to the energy addition in the translational mode by

$$F = \dot{m}\sqrt{2\left(\frac{\gamma^2 - 1}{\gamma^2}\right)}\, \sqrt{Q_{tr} + c_p\, T_{o_1}} - p_{cell}\, A \tag{10}$$

Equation (10) is used in the calculation of Q_{tr} from the measured thrust for a given generator operating condition.

Under the assumption that all the energy, Q_G, is added to the gas upstream of the sonic throat, the amount of energy added in the form of excitation and ionization energy therefore is

$$Q_{ei} = Q_G - Q_{tr} \tag{11}$$

If the entire amount, Q_{ei}, produces ionization, the fraction of gas ionized will be

$$\alpha^* = \frac{m\, Q_{ei}}{V_i} \tag{12}$$

A calculation for a typical measured thrust of 0.4 lb_f indicated a static temperature of 1150°R at the sonic station. Most ionization of the gas is thus not produced thermally, i.e., by collisions of the gas atoms with one another, but rather is produced by the direct interaction of the arc with the gas. The maximum possible overall degree of ionization for this condition, as calculated from Eq. (12), is 1.2 percent. Thus, the assumption that the specific heat capacities remain very near the cold gas values is justified.

It is desirable to be able to predict the division of energy addition in the different modes simply from the generator operating conditions without an actual thrust measurement. A comparison was, therefore, made of the measured thrust and the ideal thrust that would be produced by the plasma generator if there were no impulse losses in the anode flow region. This comparison is shown in Fig. 5. The ideal thrust is based on the momentum flux across the entrance plane of the heating zone rather than across the exit plane, and is, therefore, given by

$$F_i = \dot{m}\, v_1 + (p_1 - p_{cell})\, A \tag{13}$$

With the assumptions of local one-dimensional flow and perfect gas behavior, the ideal thrust can be expressed in terms of p_{o1}, p_{cell}, A, and γ in the form

$$F_i = p_{o_1} A (1 + \gamma M_1^2)\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{-\frac{\gamma}{\gamma-1}} - p_{cell} A \tag{14}$$

where the Mach number at the anode entrance, M_1, is related to $\dot{m}$, A, p_{o1}, and T_{o1} by the following form of the mass flow equation (Ref. 2)

$$\frac{\dot{m}}{A} = \sqrt{\frac{\gamma}{R}}\, \frac{p_{o_1}}{\sqrt{T_{o_1}}}\, \frac{M_1}{\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\frac{\gamma+1}{2(\gamma-1)}}} \tag{15}$$

Under the assumption that no energy is transferred to the gas by the electric arc upstream of the anode entrance, p_{o1} and T_{o1} correspond to the values in the generator chamber. Thus, Eqs. (14) and (15) combined give a relationship between the ideal thrust and the measured generator operating parameters $\dot{m}$, p_{o_m}, and T_{o_m}.

As can be seen from Fig. 5, the ideal thrust is consistently higher than the measured thrust. The difference in the thrusts represents the loss of gas impulse from the entrance to the exit plane of the anode, which results from wall friction and the interaction of the applied electric field with charged particles of the plasma. Figure 5 shows that the loss of gas impulse is, on the average, only approximately 6 percent of the ideal thrust. A relatively good estimate of the division of the energy addition, without an actual thrust measurement, can thus be obtained by considering the flow in the anode region to experience no impulse loss. Under this condition, the ideal translational energy addition is determined from Eq. (10) based on the ideal thrust, namely

$$Q_{tr_i} + c_p T_{o_1} = \frac{(F_i + p_{cell} A)^2}{2 \dot{m}^2 \left(\frac{\gamma^2 - 1}{\gamma^2}\right)} \tag{16}$$

The ideal energy addition in the translational mode is then related to the generator operating parameters, since from Eqs. (5), (14), (15), and (16),

$$\frac{Q_{tr_i} + c_p T_{o_1}}{c_p T_{o_1}} = \frac{(1 + \gamma M_1^2)^2}{2(\gamma + 1) M_1^2 \left(1 + \frac{\gamma - 1}{2} M_1^2\right)} \tag{17}$$

where M_1 is related to the operating parameters by Eq. (15). Under this ideal condition the energy addition in the translational mode is therefore predicted by a Rayleigh heating process since Eq. (17) represents the ratio of the final to the initial total temperature for a Rayleigh heating process (Ref. 2). The amount of energy added to the gas in the translational mode for the ideal situation, Q_{tr_i}, is compared with the actual energy addition, Q_{tr}, in Fig. 6. The resulting degrees of ionization, as determined from Eqs. (11) and (12), are shown in Fig. 7 corresponding to the measured and the ideal conditions.

SECTION IV
DISCUSSION

As can be seen in Fig. 5, there is some scatter in the experimental results. The method employed to determine generator chamber conditions and thrust values involved a time lapse of approximately a minute and a half between initiation and completion of the data acquisition cycle. At times the generator operating conditions would change slightly over this period and required resetting. These changes were more pronounced at the higher powers, and it is felt that such changes which were not detected were responsible for the small scatter.

Uniformity of gas properties in the entrance and exit planes of the anode throat is contained in the assumptions. In a generator of similar design, it was found by Dooley, et al. (Ref. 3), that the arc in argon is of a random, high frequency nature. This could cause the energy addition process to be of an averaging nature, so that uniformity of gas properties might actually exist.

In the results, the maximum amount of overall ionization attainable is calculated by assuming that all energy available for excitation and ionization produces ionization. The resulting degree of ionization, which is on the order of one percent, is therefore somewhat overestimated. Saha's equation (Ref. 4), based on gas temperature, indicates that a negligible percentage of the gas would be ionized. Saha's equation, based on a typical electron temperature of 15,000°K as obtained by spectroscopic measurements (Refs. 1 and 5), predicts that approximately 40 percent of the gas should be ionized. Therefore, the actual ionization process cannot be described by the equilibrium ionization equation at either of these temperatures. This is also intuitively expected since it was shown that most ionization results from the direct interaction of the arc column and the gas.

SECTION V
CONCLUDING REMARKS

The experimental evidence indicates that, in this plasma generator, a relatively large portion of the energy addition is available for electronic excitation and ionization. But even if one assumes this entire amount of energy to produce solely ionization, the fraction of the gas that is ionized is nevertheless quite small. The amounts of thrust produced by the plasma generator further indicate that the mean gas temperature at the generator exit, and thus throughout the heating zone, is considerably less than the temperature that is required for thermal ionization. This leads one to believe that most ionization is produced by the direct interaction of the arc column with the gas. The electric arc can thus be considered as a heating element which independently raises the gas total temperature and excites and partially ionizes the gas. Conventional gas dynamic theory should, therefore, give a fair approximation for the mean plasma properties if the degree of ionization is small, whereas an energy balance on the plasma generator will determine the amount of excitation and ionization.

REFERENCES

1. McGregor, W. K., Dooley, M. T., and Brewer, L. E. "Diagnostics of a Plasma Flame Exhausting to Atmospheric Pressure." AEDC-TR-61-16 (AD269499), January 1962.

2. Shapiro, Ascher H. The Dynamics and Thermodynamics of Compressible Fluid Flow, Volume I. Ronald Press Company, 1953.

3. Dooley, M. T., McGregor, W. K., and Brewer, L. E. "Characteristics of the Arc in a Gerdien-Type Plasma Generator." AEDC-TR-61-13 (AD268410), December 1961.

4. Cobine, James Dillion. Gaseous Conductors. Dover Publications, New York, 1958.

5. Brewer, L. E. "Spectroscopy of a Supersonic Plasma, II. Excitation Temperature." AEDC-TDR-64-196 (AD447735), September 1964.

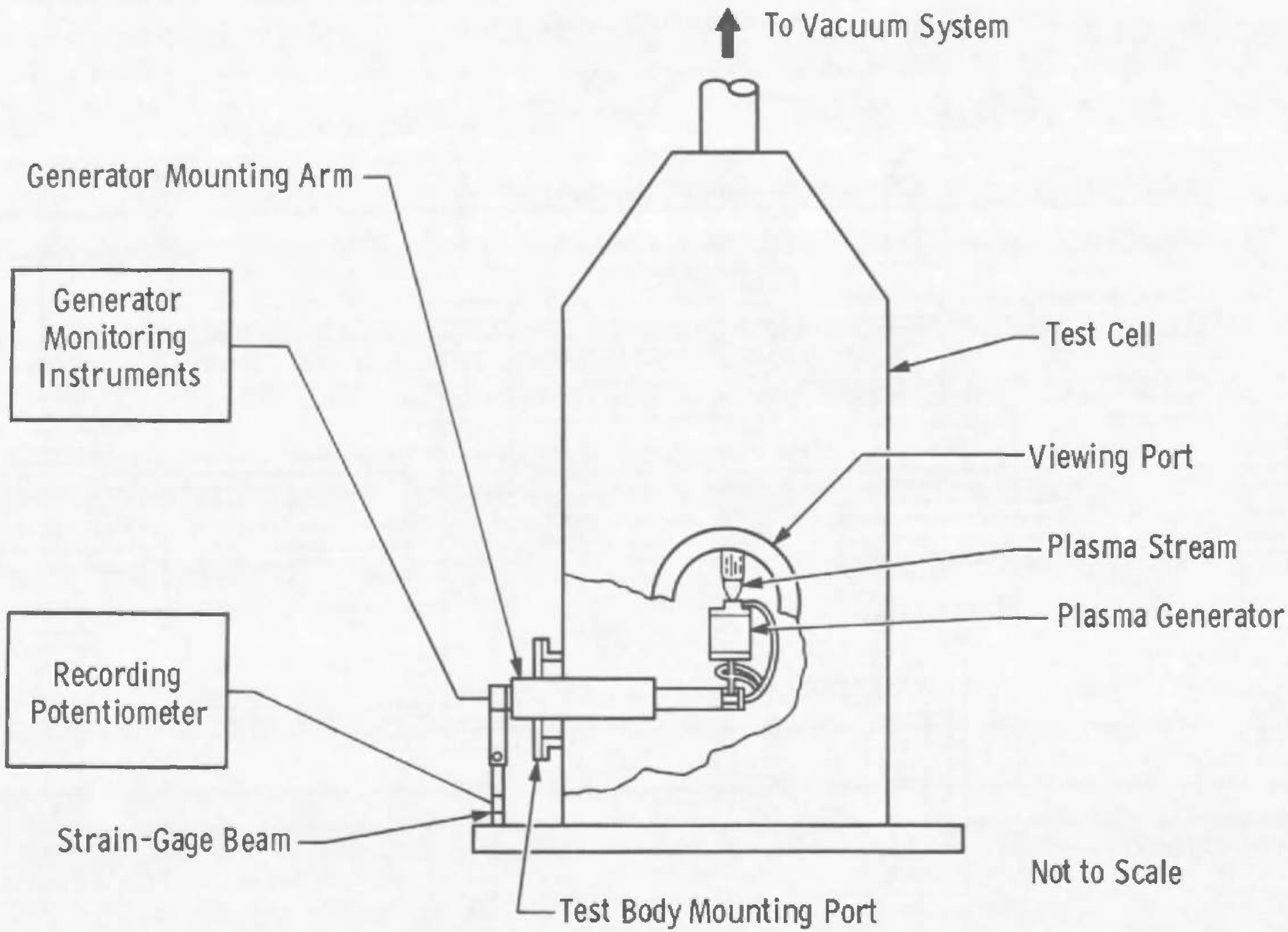

Fig. 1 Test Cell

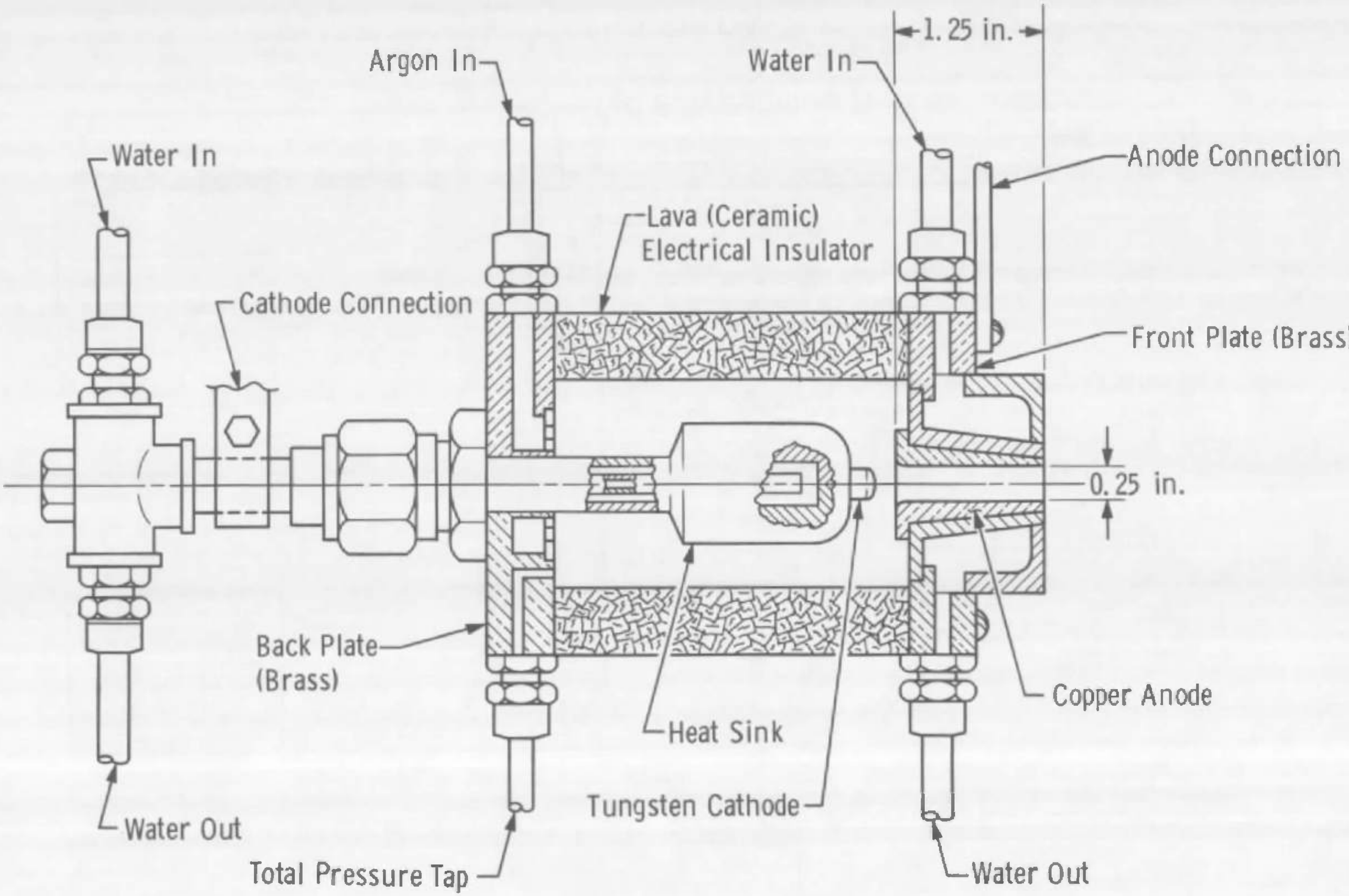

Fig. 2 Arc-Jet Plasma Generator

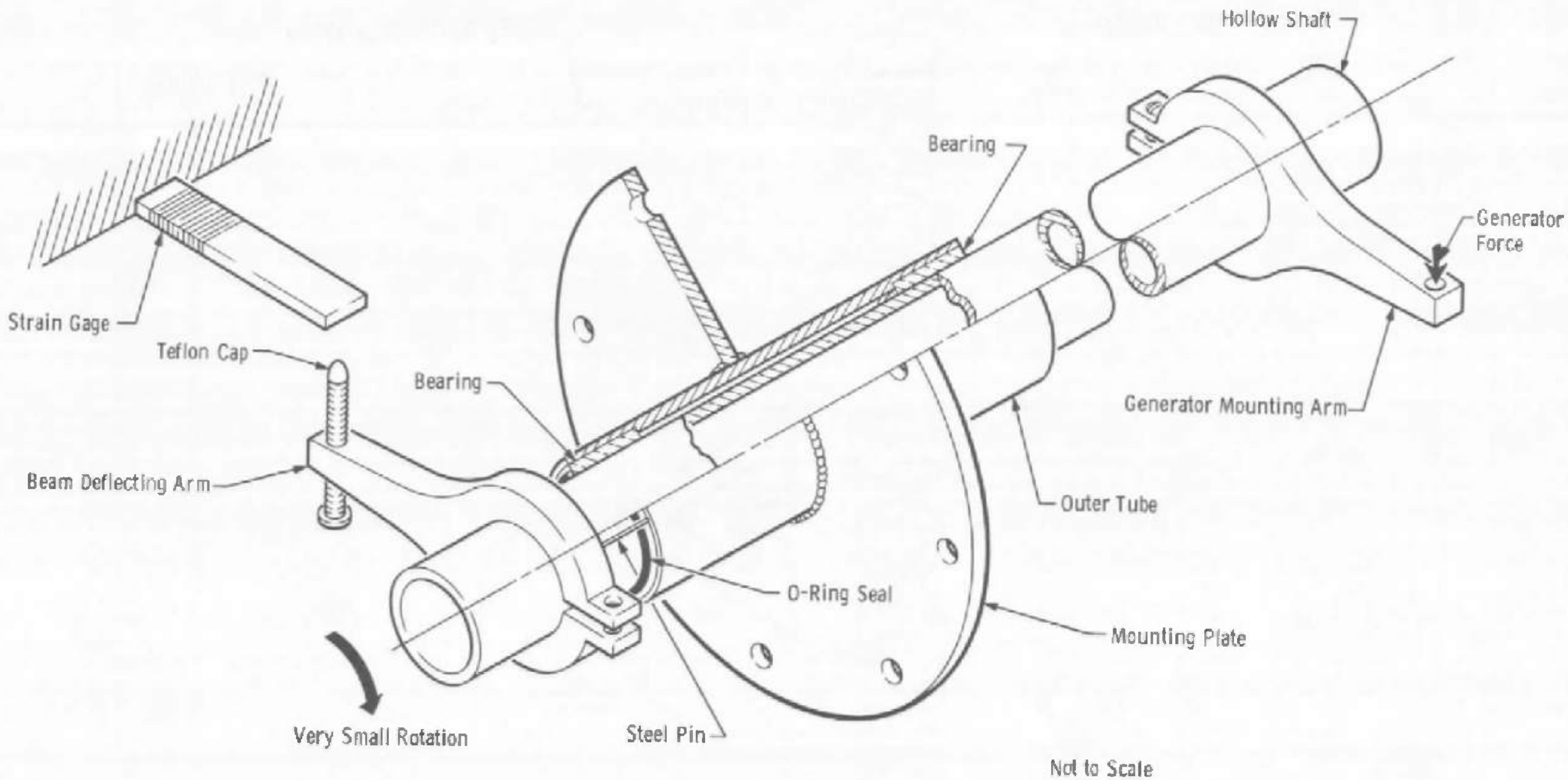

Fig. 3 Generator Support Arm

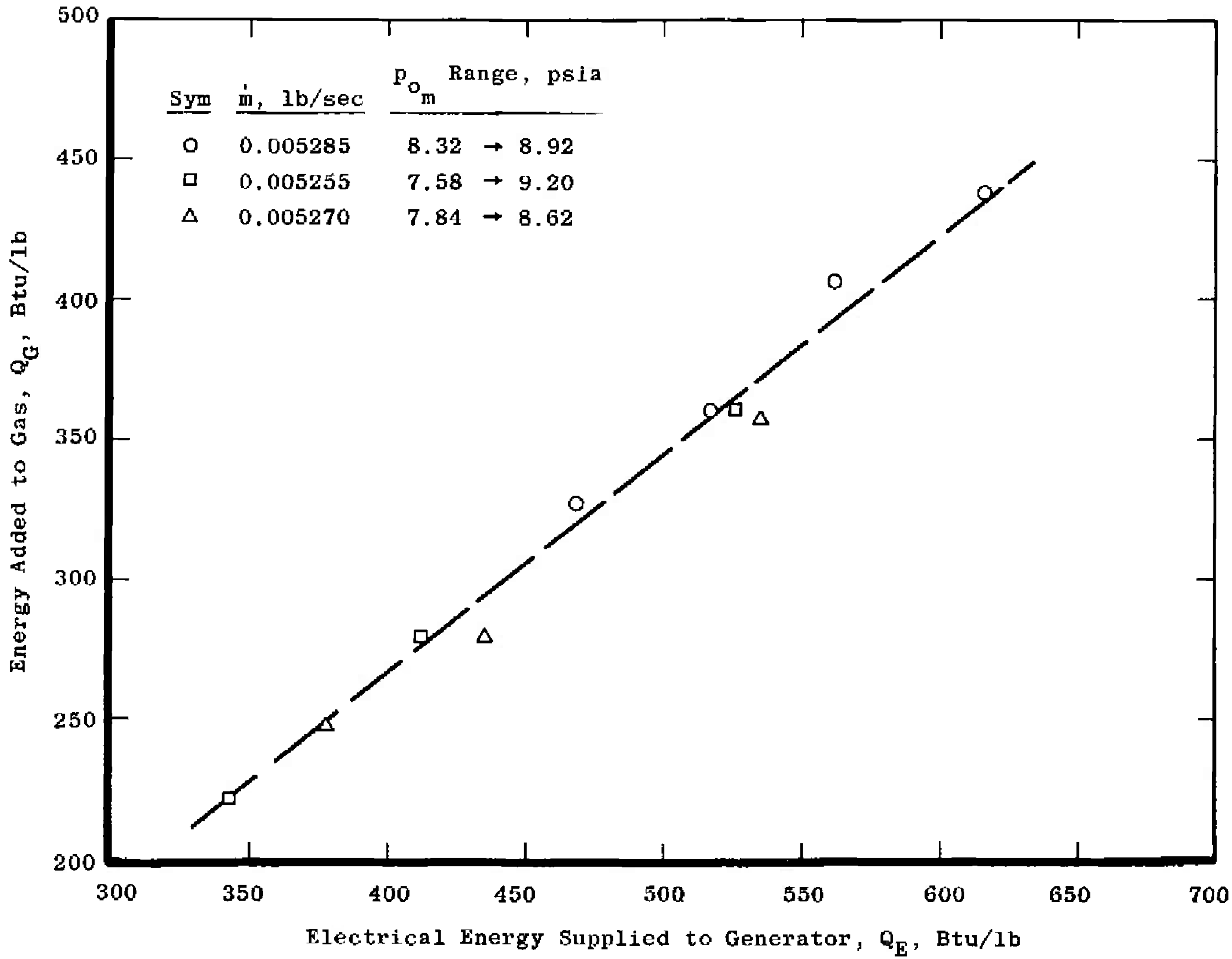

Fig. 4 Variation of the Energy Added to the Gas with Electrical Energy Supplied to the Generator

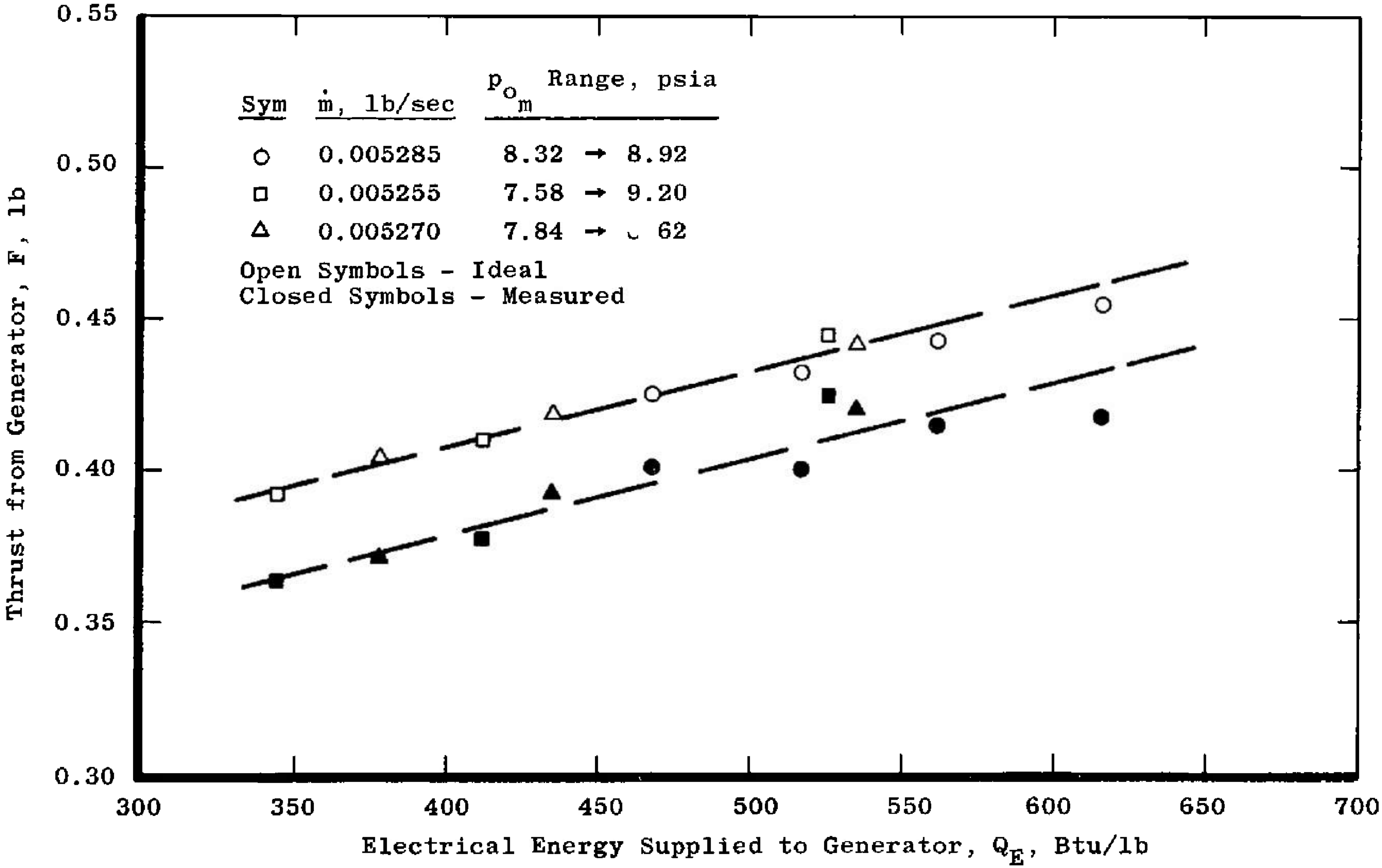

Fig. 5 Comparison of Ideal and Measured Thrusts

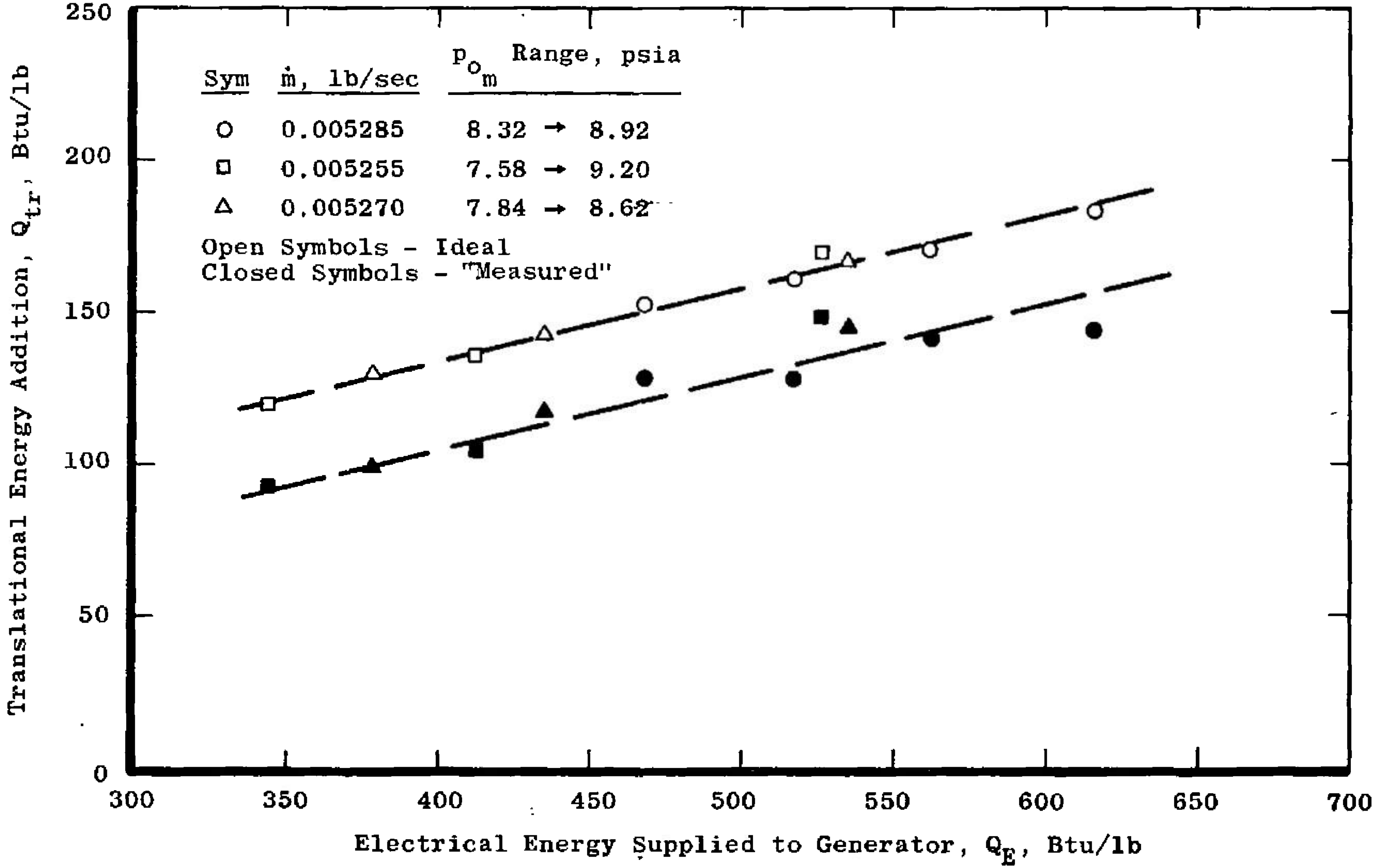

Fig. 6 Comparison of Ideal and "Measured" Translational Energy Additions

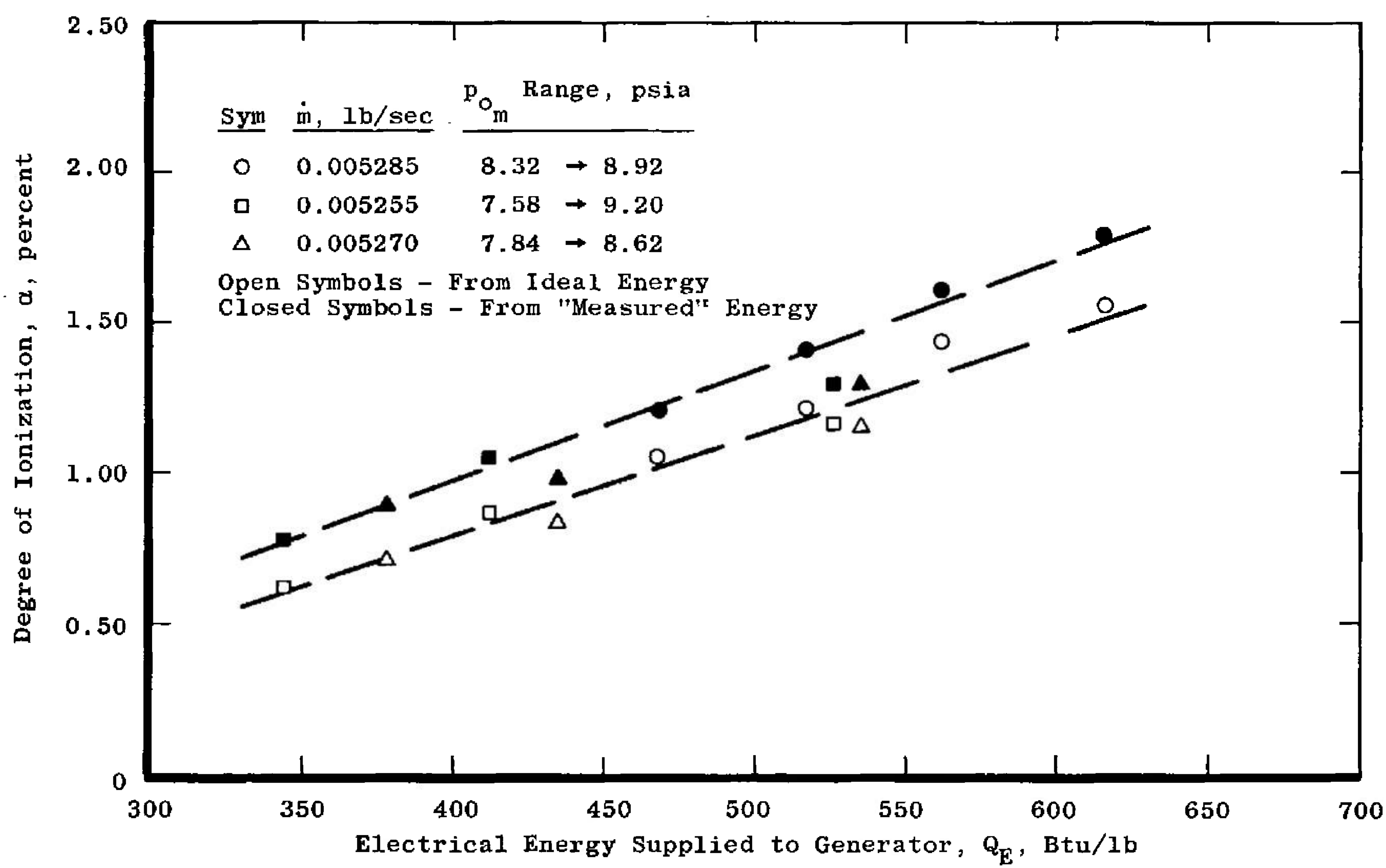

Fig. 7 Effect of the Electrical Energy Supplied to the Plasma Generator on the Degree of Ionization Produced at the Sonic Station

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Arnold Engineering Development Center (AEDC), ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N/A

3 REPORT TITLE

STUDY OF THE ENERGY ADDITION PROCESS IN A D-C ARC-JET

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5 AUTHOR(S) (Last name, first name, initial)

Bryson, R. J. and Fröhlich, J. P., ARO, Inc.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
April 1966	24	5

8a CONTRACT OR GRANT NO AF40(600)-1200 b. PROJECT NO. 8951 c Program Element 61445014 d Task 895105	9a ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-65-268 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

10 AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies from DDC, and distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
N/A	Arnold Engineering Development Center Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee

13 ABSTRACT

The thrust produced by a d-c arc-jet plasma generator operating with argon was measured and used to determine the division of the energy added to the gas between that which produced excitation and ionization and that which served to increase the translational energy of the gas. Energy division predicted by the Rayleigh heat addition theory was compared with the experimental determination and was found to be in fair agreement (15 to 30 percent). The plasma generator was operated at electrical power inputs ranging from 1.9 to 3.8 kw. Energy losses to the electrodes amounted to about 30 percent, so that about 70 percent of the total electrical energy input was actually added to the gas. The amounts of energy added to the gas ranged from 220 to 440 Btu/lb_m at an argon flow rate of 0.3162 lb_m/min. On the average, only about 40 percent of this energy addition was utilized to increase the total translational energy of the gas, and the remainder served to produce electronic excitation and ionization.

DD FORM 1 JAN 64 1473

Security Classification

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
energy addition						
arc-jet S						
1 plasma generator 15-28						
2 argon						
ionization						
excitation						
2 Plasma generators						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13 ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.